Low-cost semiconductor swept source laser for near-infrared Optical Coherence Tomography

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***Abstract*—A low-cost six-section slotted swept source laser operating at 850nm has been designed and fabricated using a standard optical lithography process. The laser is monolithically integrable without a need for any regrowth step. Initial characterization has confirmed the high quality of the slot geometry and stable single mode operation.**

***Keywords*—Optical Coherence Tomography, Semiconductor lasers**

I. Introduction

Optical Coherence Tomography (OCT) is an interferometry-based imaging technique used mainly in clinical diagnosis to examine different organs [1]. In swept source OCT, which uses spectrally scanning source, the optical frequency is encoded in time. An ideal source for an OCT system should be affordable and offer broad and continuous tuning range (~100 nm), high output power (>20 mW) and high repetition rates (~200 kHz). Over the years, wavelength-tunable semiconductor lasers have been demonstrated using external cavity, sampled Bragg gratings reflector (SG-DBR), super-structure grating distributed Bragg reflector (SSG-DBR) and surface gratings (slots) [2,3]. In particular, multi-section lasers based on etched slots [4] have attracted considerable interest at 1.55 µm due to their low cost and simple fabrication process as compared to the conventional buried lasers which sometimes require time-consuming and expensive regrowth steps. Even though swept source lasers based on semiconductor slotted lasers are available at 1.55 µm and 1.31 µm wavelength range, a comparable technology is not available at 850 nm where applications in biomedical OCT exists**.** In this paper, we describe the design and fabrication of a six-section widely tunable laser at 850 nm which utilises Vernier effect to tune output wavelength. The laser consists of a phase section, gain section, two semiconductor-optical-amplifier (SOA) sections and two mirror sections incorporating surface etched slots (cf. Fig. 1).

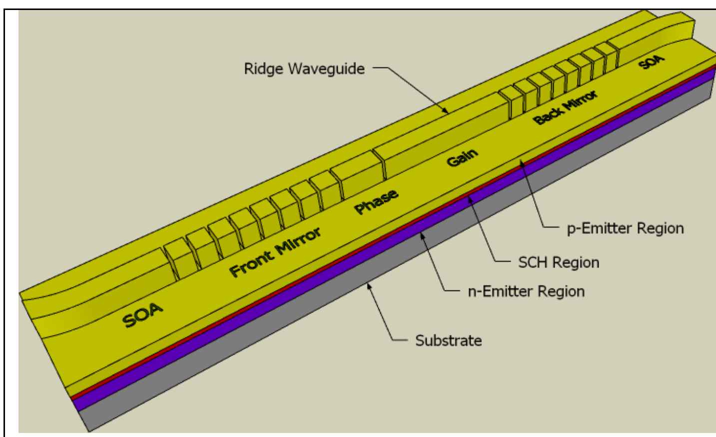

Fig 1: The schematic structure of a six-section slotted laser.

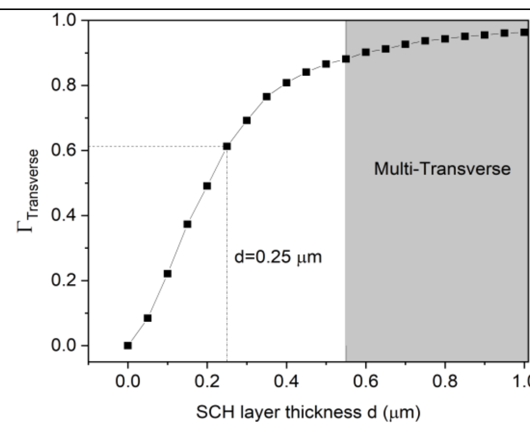

Fig 2: Transverse optical confinement factor $\Gamma_{Transverse}$ as a function of SCH layer thickness obtained using finite difference eigenmode method.

II. Design

A stable single mode operation with high side mode suppression ratio (SMSR) values is a fundamental requirement for the desired laser performance. It can be achieved for sufficiently strong optical field coupling between the slotted region and the evanescent field of the fundamental mode. Therefore, careful design optimization is a key step before the fabrication process.

A. Single mode operation

In a first step, calculations of TE and TM modes have been carried out for an AlGaAs/GaAs separate confinement heterostructure (SCH) quantum well structure emitting at 850 nm to ensure single-transverse mode operation. This is done using a finite-difference eigenmode solver which solves Maxwell's equation at the cross-section of the waveguide. The active and waveguide layer should be

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sufficiently thick so that the mode is confined within these layers without supporting multi-transverse mode. Accordingly, we plot the transverse confinement factor ($\Gamma_{Transverse}$) in Fig. 2, where the shaded area denotes multi-transverse mode operation for the laser structure at 850 nm. The waveguide layer in the laser structure has a thickness of 0.25µm (dotted line) and satisfies the single transverse mode operation with an $\Gamma_{Transverse}$ of 0.61. Similarly, the width and depth of the ridge section are optimized with the ridge width (depth) of 2 (1.7) µm to support a lateral single mode operation while ensuring high reflection.

B. Optimization of slot parameters

The slot parameters such as period (width and spacing), depth, and the number of slots have been carefully optimized to obtain the required laser performance. Tunability is achieved through Vernier tuning where the periodicity of the slots in the front and back mirrors are slightly different in order to have a wide tuning range (λ_{tuning}) of ≈80 nm. λ_{tuning} is calculated using the expression(($\lambda_f\lambda_b$)/λ_f-λ_b)), where λ_f and λ_b are free spectral ranges (FSRs) for the front and back mirrors respectively. The slots act as high order surface gratings and their period is optimized to be between 25-27 µm ($m\lambda_B/2n_{eff}$) which gives FSRs around 4 nm. Here, λ_B= 850 nm, n_{eff} is the average effective refractive index and m is the grating order. The slot width is optimized to be around 1µm to ensure compatibility with standard optical photolithography process. In the preliminary design, ridge and slot depth is the same as they both are etched in the same process step. Ten slots are used in both mirror sections to provide a sufficient amount of reflection for the lasing operation keeping in mind the narrow bandwidth required for stable single mode operation.

III. Fabrication and characterization

The six-section laser (cf. Fig. 1) has been fabricated using standard optical photolithography where all sections are electrically isolated by incorporating additional slot between them. A 300 nm oxide mask has been used for slots and ridge chlorine-based ICP etching process which ensured high-quality sidewalls profiles. Apart from a small residual layer (~200 nm), the whole upper cladding was etched in the slot region to obtain required reflectance with minimal transmission loss. An experimental setup for electro-optical characterization of the laser has been set up. After mounting the laser on a thermo-electric cooler, five current sources were used to inject the current into the gain, phase, SOA_1, and both mirror sections. The laser spectrum of the device (cf. Fig 4) has been recorded for a fixed gain, phase and mirror currents using an optical spectrum analyzer. Subsequently, the currents injected into the front and back mirror sections are varied to achieve Vernier tuning. In the next step, wavelength maps as a function of both mirror currents for the whole tuning range will be measured in order to determine stable single mode regions without sudden mode hops.

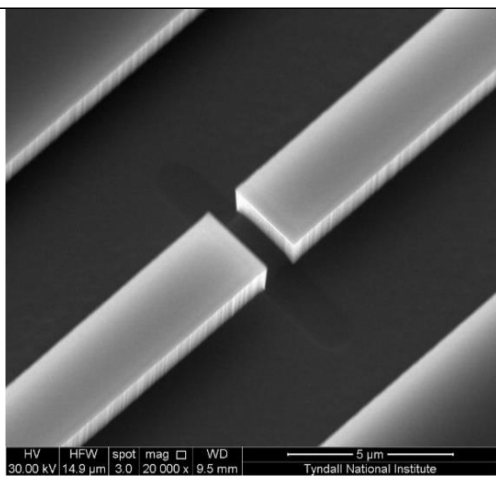

Fig 3: SEM images of the slotted ridge waveguide and a single slot.

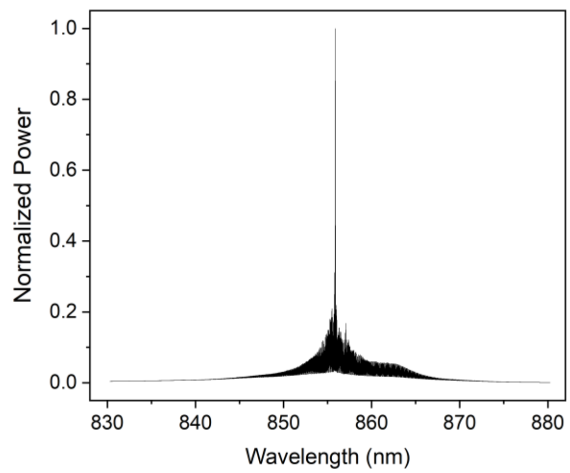

Fig 4: Output laser spectrum for a fixed gain, phase and mirror currents

IV. Conclusion

In conclusion, we demonstrated the fabrication of a low-cost stable single mode tunable laser at near-infrared wavelength. Initial characterizations indicate the laser can be a potential source for the OCT applications.

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